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METHOD AND APPARATUS FOR
DETECTING FRACTURES USING FREQUENCY
DATA DERIVED FROM SEISMIC DATA

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CROSS REFERENCE TO RELATED APPLICATIONS

15   This is a utility application of prior pending provisional
application serial number 60/353,698 filed January 31, 2002,
and entitled ``Detecting Fractures with frequency data
derived from P-wave seismic data''.

20   BACKGROUND

The subject matter of the present invention relates to a
method and apparatus responsive to a plurality of seismic
data for generating a map illustrating data representative
25   of a frequency shift of a plurality of seismic signals when
said seismic signals propagate through a layer of fractured
rock in an Earth formation.

Geologic formations containing fractures are an important
30   source of hydrocarbon accumulations and an interesting
target for geophysical exploration. The presence of
fractures in a geologic formation will act as a high-cut
filter with respect to the seismic wave that is propagating

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through the layer of fractured rock in the Earth formation. This produces a measurable and mappable change in the frequency spectra of the seismic signal propagating above the fractured zone compared to the frequency spectra of the

5   seismic signal propagating below the fractured zone.

SUMMARY

Accordingly, in accordance with the present invention, a

10   unique method has been developed which can show the presence of fractures in an Earth formation as a mappable attribute. This method, described in the Detailed Description hereinbelow, uses the frequency spectra derived from P-wave seismic data, comprised of a plurality of seismic traces,

15   over a pair of specific time windows, which are located above and below a seismic horizon or reflector of interest, to infer the presence or absence of these geologic fractures, in a layer of fractured rock, based on the preferential attenuation of high frequencies. The method

20   produces a parameter $(t*)$, the parameter $t*$ being proportional to the shift in frequency spectra amplitudes (i.e., energy), from higher frequencies to lower frequencies, when the plurality of seismic traces propagate from the time-window located above the seismic horizon or

25   reflector of interest, through the layer of fractured rock, to the time-window below the seismic horizon or reflector of interest. A map is generated based on the computation of $t*$ for all seismic traces in the seismic data.

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Further scope of applicability of the present invention will
become apparent from the detailed description presented
hereinafter. It should be understood, however, that the
detailed description and the specific examples, while

5   representing a preferred embodiment of the present
invention, are given by way of illustration only, since
various changes and modifications within the spirit and
scope of the invention will become obvious to one skilled in
the art from a reading of the following detailed

10   description.

BRIEF DESCRIPTION OF THE DRAWINGS

A full understanding of the present invention will be

15   obtained from the detailed description of the preferred
embodiment presented hereinbelow, and the accompanying
drawings, which are given by way of illustration only and
are not intended to be limitative of the present invention,
and wherein:

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Figure 1 illustrates a workstation with a CD-Rom adapted to
be inserted therein for loading a workstation software
package known as the 'Fracture Detection Software' in
accordance with the present invention;

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figure 2 illustrates a layer of fractured rock in an Earth
formation;

figures 3 and 9 illustrate the layer of fractured rock including a first window above the fractured rock zone and another, second window below the fractured rock zone;

5   figure 4 illustrates the frequency spectrum of the seismic signal in the first window of figure 3;

figure 5 illustrates the frequency spectrum of the seismic signal in the second window of figure 3;

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figures 6 and 10 illustrate the frequency spectra of figures 4 and 5 superimposed upon one another defining six measurement values;

15   figure 7 illustrates formula for defining 'F high', 'F low', and t*; and

figures 8 and 11 illustrate a map of the fractured rock zone of figures 2 and 3, which maps the attribute t*.

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DETAILED DESCRIPTION

Referring to figure 1, a workstation or other computer system 30 is illustrated. The computer system 30 may be,

25   for example, a personal computer, a workstation, a mainframe, etc. Examples of possible workstations include a Silicon Graphics Indigo 2 workstation and a Sun SPARC workstation. The computer system 30 stores and executes a plurality of instructions that are used to detect fractures

30   in an Earth formation in response to a plurality of seismic

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data 33, the seismic data 33 being provided as 'input data' to the computer system 30. The computer system 30 of figure 1 includes a processor 30a, a recorder to display device 30b, a memory 30c which is adapted to store the

5   'Fracture Detection Software' 30c1 in accordance with the present invention, and a system bus 30d to which the Processor 30a and the recorder or display device 30b and the memory 30c are connected. A CD-Rom 32 stores the 'Fracture Detection Software' 30c1 of the present invention, and, when

10   the CD-Rom 32 is inserted into the computer system 30, the Fracture Detection Software 30c1 is loaded from the CD-Rom 32 into the memory 30c of the computer system 30. The processor 30a can now execute the 'Fracture Detection Software' 30c1 instructions and perform its fracture

15   detection for detecting fractures in an Earth formation.

The process steps being practiced by the 'Fracture Detection software' 30c1 of the present invention, when the instructions of the fracture detection software 30c1 are

20   being executed by the processor 30a of the computer system 30 of figure 1, will be set forth below followed by an explanation of each of those process steps.

Process Steps

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The following steps represent the process steps practiced by the Fracture Detection software 30c1 of figure 1:

1.   Interpret the reflector (horizon) on the seismic data,

30   recording the two-way seismic travel time.

2.   The interpreter specifies the length of the time window
(e.g., 100 milliseconds) to extract the frequency spectra.

5   3.   The same time window length is recommended, but not
required, on the seismic trace above and below the
reflector.   This window will be relative to the travel time
of the interpreted horizon (see step 1); that is, the window
will be parallel to the geologic structure.

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4.   For every seismic trace where the horizon is
interpreted, the interpreter generates two spectra; that is,
a first spectra located above the horizon, and a second
spectra located below the horizon.   This operation can be

15   performed using any number of transforms which result in a
frequency representation of the data, i.e., Fast Fourier
Transform, Wavelet Transform, Cosine Correlation, etc.

20   5.   The interpreter extracts amplitudes for two specific
frequencies (i.e., 10Hz and 30Hz) from the spectra above and
below the horizon.   The objective is to select a high and
low frequency from the spectra of each window (above and
below the horizon) which are separated as far as possible in

25   the usable bandwidth of the signal yet still contain valid
amplitude (energy) above the background noise level. This
can be generalized to any technique that measures the change
in the energy (amplitude) distribution for the window above
the horizon and the window below the horizon.

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6. The amplitude values are used as input to the algorithm which compute the 't*' parameter for that seismic trace. The computation of t* is as follows:

F(high) = Fa(high) / Fb(high);

F(low) = Fa(low) / Fb(low)

t* = { ln[F(high)] - ln [F(low)] } / (high - low)

where;

F(high) is the ratio of the amplitudes for the higher frequency selected by the user (30 hz for the example) taken from the window above, Fa(high), and the window below, Fb(high);

F(low) is the ratio of the amplitudes for the lower frequency selected by the user(10 hz for the example) taken from the window above, Fa(low), and the window below, Fb(low); and

t* is the computed attribute taken from the difference in the natural log (ln) of F(high) and F(low) and this difference then scaled (divided) by the difference in frequency between the measurement points on the spectra (for the example: 30hz - 10hz = 20hz, 20 was used in the denominator of the t* formula).

7.   These steps are applied to every interpreted seismic
trace.

8.   The results (i.e., the t* parameter) are plotted on a
5   map of the seismic survey. Areas of large t* values are more
likely to contain a fractured formation. This map is
generated using existing software, provided by Schlumberger
Technology Corporation of Houston, Texas, for visualizing a
seismically derived attribute in a spatial context.
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Explanation of the Process Steps

Referring to figure 2, a layer of fractured rock in an Earth
formation is illustrated. In figure 2, a layer of fractured
15   rock 34 is located beneath the Earth's surface 36. Assume
that an acoustic or explosive energy source 38 generates
sonic vibrations or sound waves 40 and those sound waves 40
reflect off a horizon 42 in the Earth's formation. The
reflected sound waves 40a are received by a geophone 44 and,
20   as a result, a plurality of seismic traces are recorded in a
recording truck 46. Lets examine carefully only 'one such
seismic trace' among the plurality of seismic traces
recorded in the recording truck 46.

25   Referring to figures 3 and 9, the 'one such seismic trace'
48 is illustrated in connection with the layer of fractured
rock 34 in the formation of figure 2. In accordance with
the novel method of the present invention, begin the steps
of that method by selecting a window 50 along the seismic
30   trace 48 which is disposed above the fractured rock zone,

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and another window 52 along the seismic trace 48 which is disposed below the fractured rock zone.

Referring to figure 4, generate a frequency spectrum of that portion of the seismic trace 48 which is disposed in the window 50 above the fractured rock zone 50. That frequency spectrum, which is associated with that portion of the seismic trace 48 which is disposed inside the window 50 above the fractured rock zone 50 (hereinafter referred to as ``Above'') is illustrated in figure 4. The frequency spectrum ``Above'' of figure 4 can be generated by using the Fast Fourier Transform or a `Cosine Correlation Transform'. One example of the use of the Fast Fourier Transform is illustrated in U.S. Patent 5,870,691 to Partyka et al, the disclosure of which is incorporated by reference into this specification. In addition, one example of the use of the `Cosine Correlation Transform', is disclosed in U.S. Patent application serial number 10/017,565, filed 12/14/01, entitled ``Seismic signal processing method and apparatus for generating correlation spectral volumes to determine geologic features'', the disclosure of which is also incorporated by reference into this specification.

Referring to figure 5, generate a frequency spectrum of that portion of the seismic trace 48 which is disposed in the window 52 below the fractured rock zone 52. That frequency spectrum, which is associated with that portion of the seismic trace 48 which is disposed inside the window 52 below the fractured rock zone 52 (hereinafter referred to as ``Below'') is illustrated in figure 5. The frequency

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spectrum ``Below'' of figure 5 can be generated by using the Fast Fourier Transform or a `Cosine Correlation Transform'. One example of the use of the Fast Fourier Transform is illustrated in U.S. Patent 5,870,691 to Partyka et al, the

5   disclosure of which has already been incorporated by reference into this specification. In addition, one example of the use of the `Cosine Correlation Transform', is disclosed in U.S. Patent application serial number 10/017,565, filed 12/14/01, entitled ``Seismic signal

10 processing method and apparatus for generating correlation spectral volumes to determine geologic features'', the disclosure of which has already been incorporated by reference into this specification.

15 Referring to figures 6 and 10, a frequency spectrum is illustrated, where the frequency spectra of figure 4 (i.e, `Above') is superimposed over the frequency spectra of figure 5 (i.e., `Below'). In the frequency spectrum of figure 6, select a low frequency `Low' and a high frequency

20 `High' along the `x' frequency axis. Using the `Low' frequency in figure 6, locate an amplitude on the `y' amplitude axis of the `Above' frequency spectra, `Fa(low)', and locate an amplitude on the `y' amplitude axis of the `Below' frequency spectra, `Fb(low)'.   Using the `High'

25 frequency in figure 6, locate an amplitude on the `y' amplitude axis of the `Above' frequency spectra, `Fa(high)', and locate an amplitude on the `y' amplitude axis of the `Below' frequency spectra, `Fb(high)'. Now, as noted in figure 6, six different values or measurements have been

30 defined, as follows: (1) Low, (2) High, (3) Fa(low),

(4) Fb(low), (5) Fa(high), and (6) Fb(high). Each of these six values or measurements will be used in an algorithm to be described below with reference to figure 7.

5 Referring to figure 7, define the value 'F high' as follows:

F high = Fa(high)/Fb(high)

Define a value 'F low' as follows:

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F low = Fa(low)/Fb(low)

From the values 'F high' and 'F low', define an attribute hereinafter called the ''t* attribute'', as follows:

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t* = [ln (F high) - ln (F low)]/(High - Low)

Referring back to figure 3, the t* attribute can be defined as follows: recalling that the seismic trace 48 has a

20 particular frequency before the trace 48 propagates through the layer of fractured rock 34, the t* attribute represents an indication of how much that frequency (of the seismic trace 48) shifts or changes when the seismic trace 48 propagates through the layer of fractured rock 34 in

25 figure 3.

Referring to figure 8, recalling that the seismic trace 48 of figure 3 intersected the horizon 42 at a location on the horizon which is defined by the (x, y) coordinates (x1, y1),

30 a 'map of the fractured zone' can be plotted. On the 'map',

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plot the above defined 't*' attribute on the 'map' at the same coordinate location (x1, y1). Recall that the seismic trace 48 intersected the horizon 42 at coordinate location (x1, y1). Then, assign a unique color to the 't*' attribute

5 which is plotted on the map, the unique color corresponding directly to the t* attribute value plotted on the map. For each t* attribute value plotted on the map, assign a corresponding and possibly different and unique color to each t* attribute. As a result, a user can see the color on

10 the map and associate the color on the map to a unique t* attribute value.

Referring to figure 11, the above process plotted the t* attribute on the 'map' using a single seismic trace 48.

15 Repeat the above process for all the other seismic traces which are recorded by the geophone 44 representative of the reflected sound vibrations 40a of figure 2. When the above process is repeated for all the other seismic traces, the ''map of the Fractured Zone'' of figure 11 will be the

20 result.

The invention being thus described, it will be obvious that the same may be varied in many ways. Such variations are not to be regarded as a departure from the spirit and scope

25 of the invention, and all such modifications as would be obvious to one skilled in the art are intended to be included within the scope of the following claims.